Linear Collider Damping Rings

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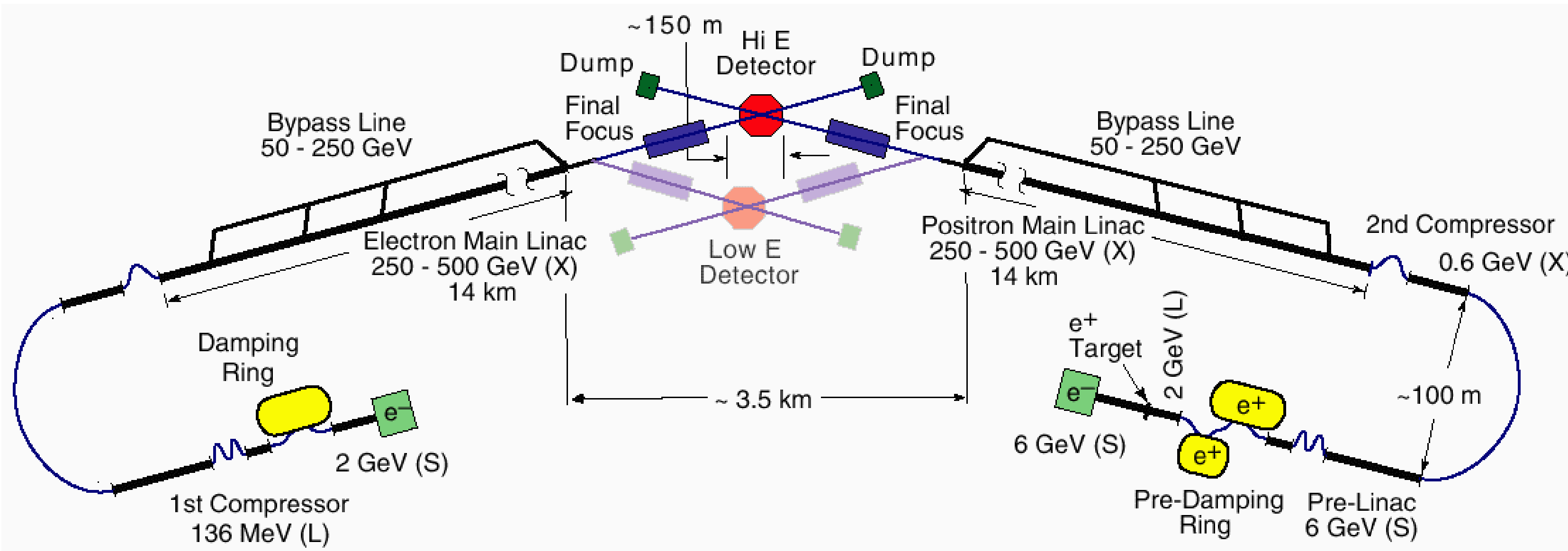
Linear Collider success depends on DR performance

- NLC design luminosity 2×10^{34} cm^{-2}s^{-1} at 500 GeV center of mass
  - Luminosity is a critical parameter for discovery potential
  - Beam needs low emittance, high intensity, excellent stability
  - Damping ring design and operation are crucial to LC performance



- LBNL has ownership of NLC Damping Rings
- Studies encompass both warm and cold machines
  - LBNL made a significant contribution to the work of the International Linear Collider Technical Review Committee (A. Wolski)

Collective effects a serious issue for 2001 NLC designs

- LBNL produced designs for 2001 NLC Configuration
  - Lattice designs for Damping Rings and Transport Lines
  - All major systems and components included
  - Met specifications for acceptance and extracted emittance
  - Minimized length of damping wiggler
    - Concerns about beam dynamics impact from SPEAR2 experience
    - Relatively short wiggler led to a short bunch length

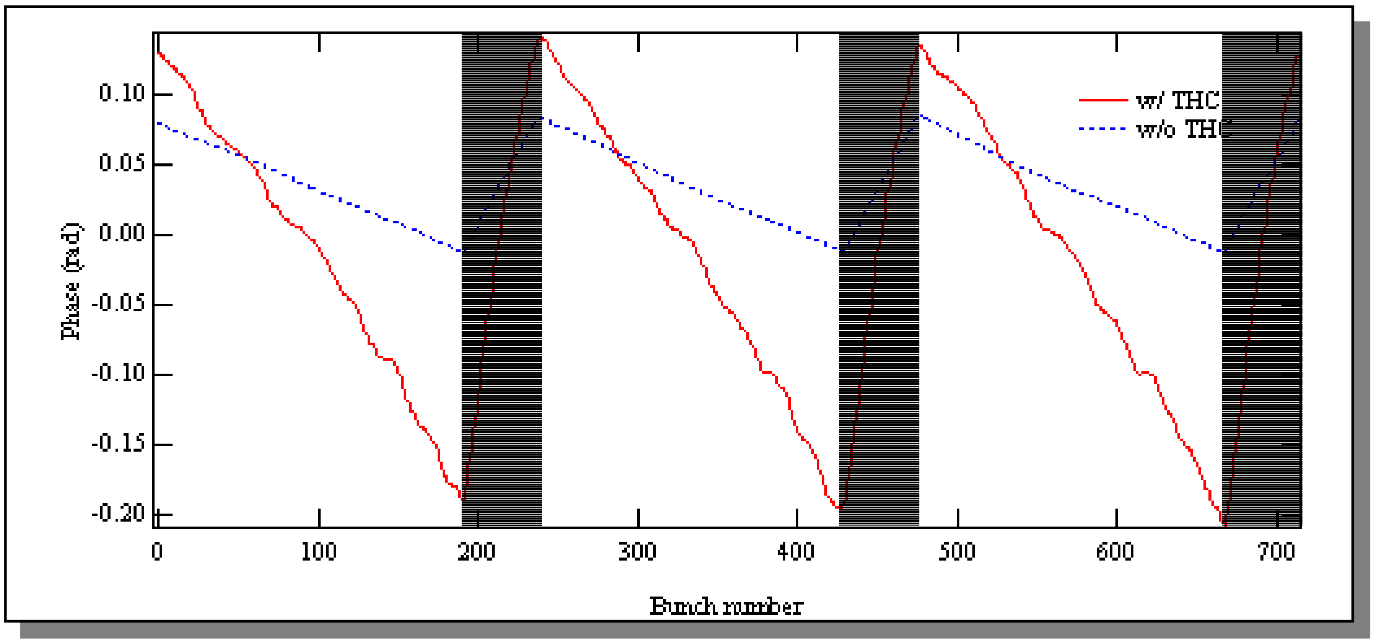
- Studies continued through 2001/2002
  - Dynamic aperture limitations by sextupoles and wiggler
  - Alignment and tuning for low vertical emittance
  - Collective effects

- Dynamic aperture OK

- **Close to threshold for some collective effects**
  - ***Can we use harmonic cavities to lengthen the bunch?***

Harmonic cavities induce large phase transients

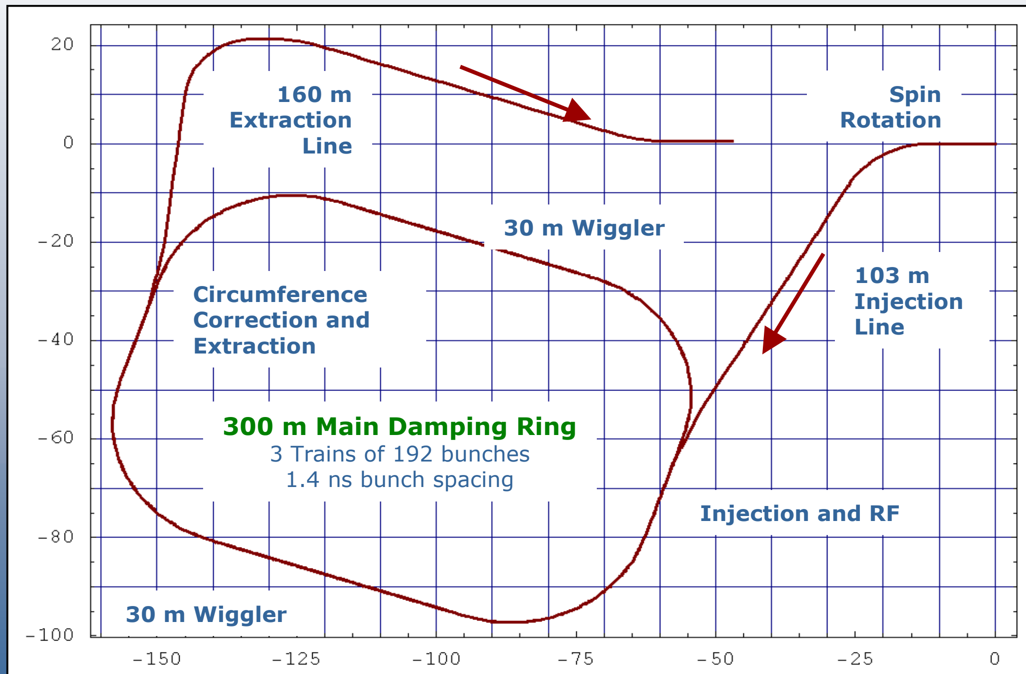
- Harmonic cavities are used in several light sources, including the ALS
- For damping rings, phase variation along the train should be <80 mrad
  - Phase variation comes from the effect of a gap in the bunch train on beam loading in the (main and harmonic) cavities
  - Some linear phase variation can be corrected in the bunch compressors before the main linac

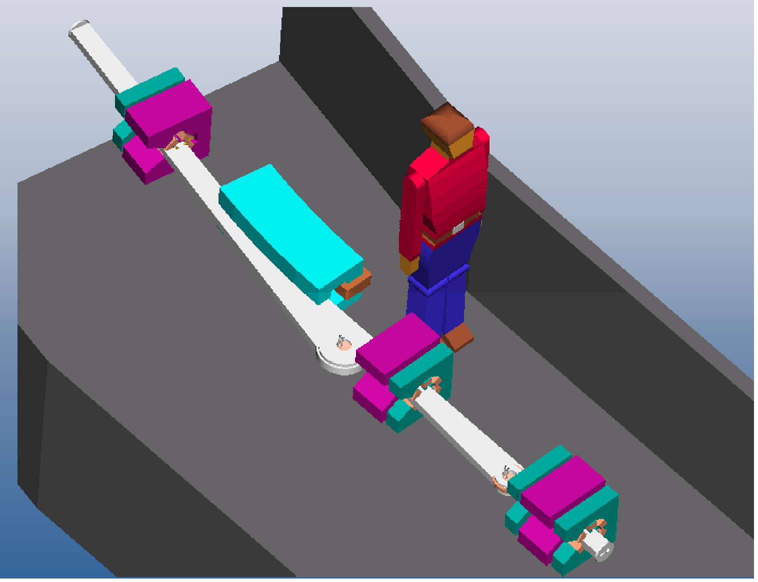


- 30% bunch lengthening increases phase transients from 80 mrad peak-to-peak, to 350 mrad peak-to-peak

2003 NLC Configuration: New lattice for a longer bunch

- New lattice designs for NLC Main Damping Rings
  - Reduce dipole field, increase the bunch length by 50%
  - Significantly reduce impact of collective effects
  - Need an additional 20 m of wiggler in each ring





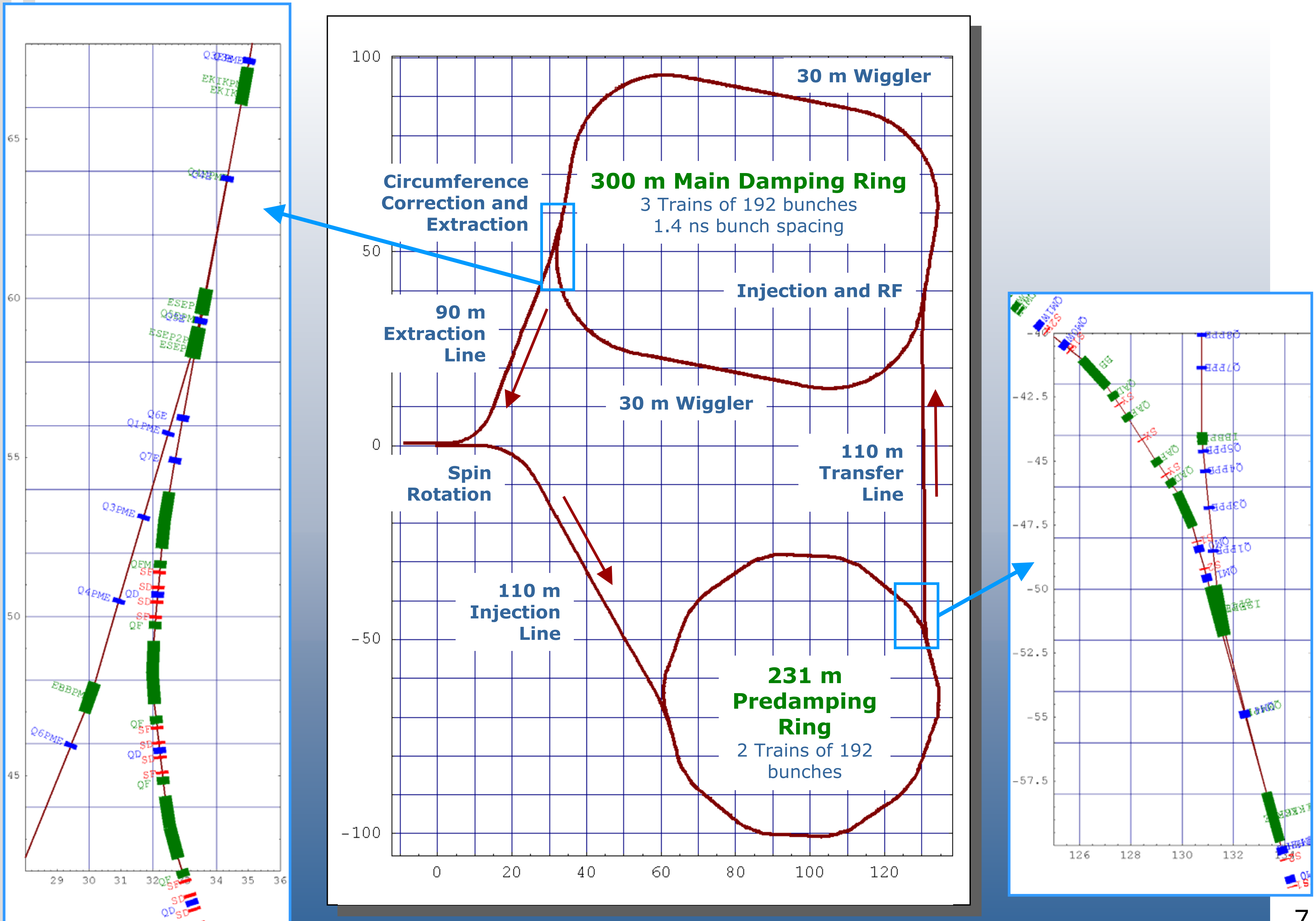
- Positron Predamping Ring also improved
  - Reduced emittance
  - Increased dynamic aperture
- New Transport Lines
  - 180 m reduction in tunnel length

New NLC DR lattice has eased most collective effects

- Microwave Instability and Coherent Synchrotron Radiation
  - Growth in energy spread above a threshold bunch charge
- Intrabeam Scattering
  - Growth in transverse emittance
- Resistive Wall
  - Growth of multibunch oscillations
- Fast Ion Instability
  - Ions generated during the passage of a single bunch train drive oscillations along the train
  - Theoretical models need quantitative verification

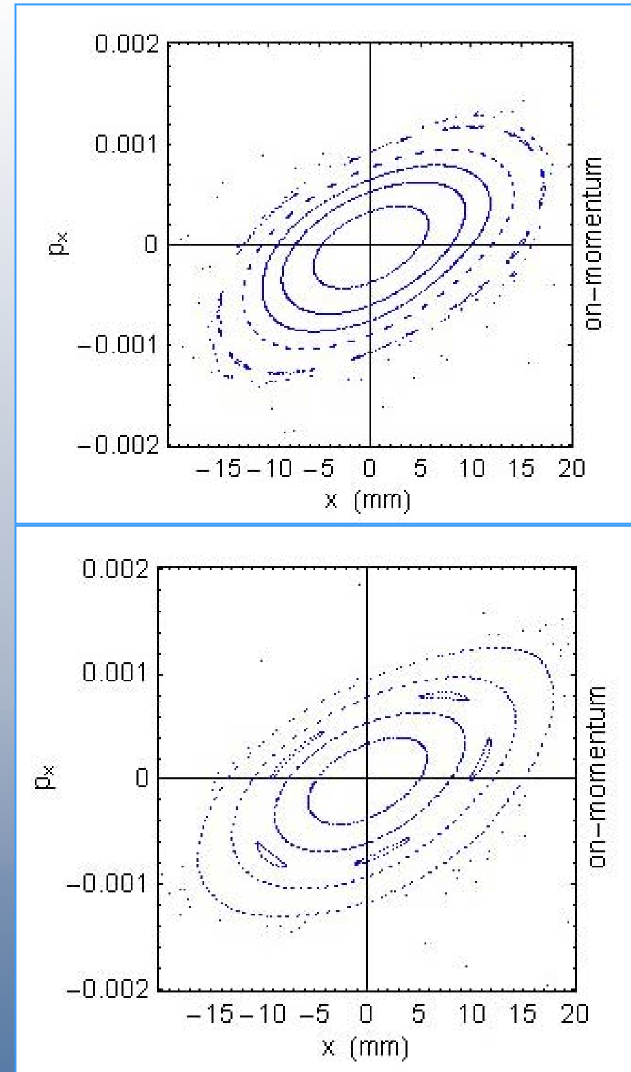
Effect	Parameter	Specification	2001 Lattice	2003 Lattice
Microwave	Bunch charge	0.75×10^{10}	$<1.9\times10^{10}$	$<15\times10^{10}$
CSR	Bunch charge	0.75×10^{10}	$<1.0\times10^{10}$	$<6.6\times10^{10}$
IBS	Horizontal emittance	3 μm	3.5 μm	2.9 μm
	Vertical emittance	0.02 μm	0.022 μm	0.021 μm
Resistive Wall	Growth time	-	125 μs	106 μs

A new layout for the NLC Positron Damping Rings



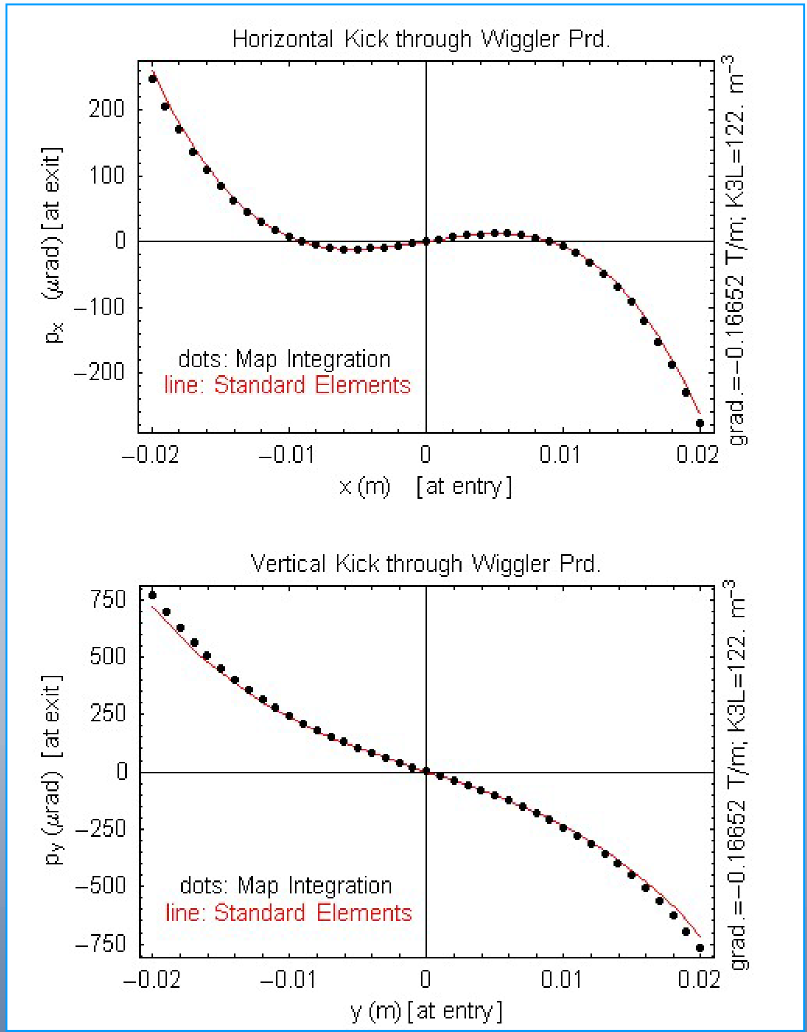
New tools developed for dynamics in wigglers

- Damping Rings have high average injected beam power
  - 55 kW for NLC
  - 226 kW for TESLA
  - Need ~100% injection efficiency
- Dynamic aperture is limited by:
  - Sextupoles
  - Wiggler
  - Systematic and random errors
- To study the wiggler effects, we need:
  - Accurate field representation
  - Symplectic integrator
- New tools developed for studying damping ring wigglers
  - Applied to NLC and TESLA
  - Can be applied to insertion devices in light sources, circular colliders…

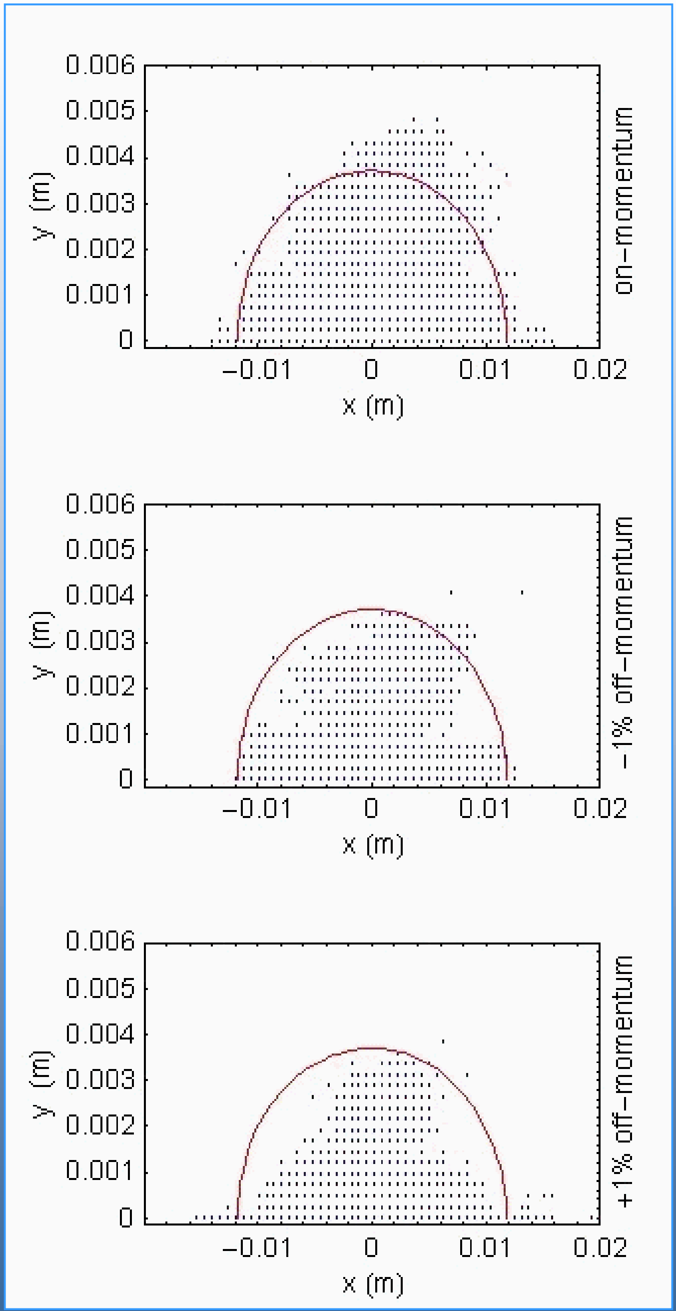


Horizontal phase space produced using (top) wiggler modeled by standard lattice elements, (bottom) accurate field model.

NLC wiggler allows reasonable dynamic aperture



Horizontal and vertical kicks in one period of the wiggler.



Dynamic aperture calculated by tracking 500 turns, including sextupole and wiggler nonlinearities, no longitudinal dynamics. Red ellipse shows 15× injected beam size.

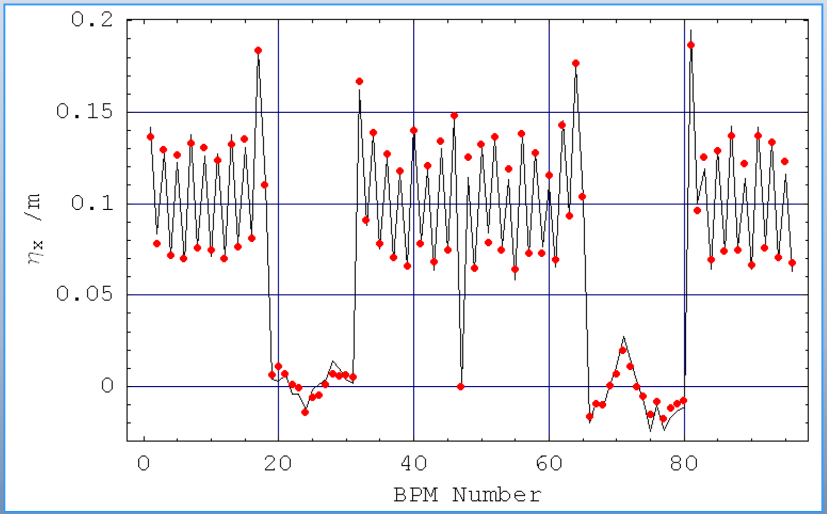
Vertical emittance is a challenging issue

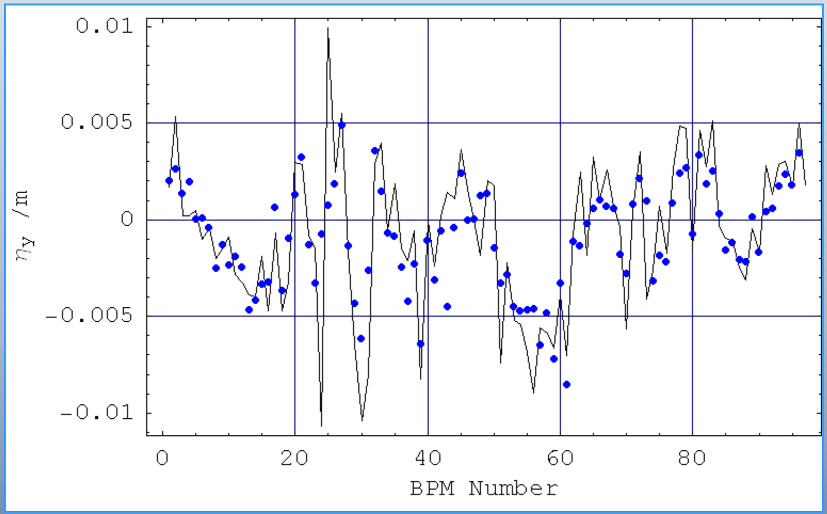
- Specified equilibrium vertical emittance in NLC MDR is 5 pm
  - Demanding requirement on alignment and coupling correction
- Extracted beam jitter should be less than vertical beam size
  - Sets limit on allowable vibration of the quadrupoles
- NLC MDR is *less sensitive* than ALS to sextupole vertical misalignments and quadrupole rotations

	NLC MDR	TESLA DR	ALS	KEK-ATF	SLS
Energy [GeV]	1.98	5	1.9	1.3	2.4
Circumference [m]	300	17,000	197	139	288
Damping time [ms]	3.6	25	7.3	10	9
Horizontal emittance [nm]	0.77	0.82	6.9	1.1	5.0
Vertical emittance [pm]	5.1	1.4	5	10	15
Sextupole alignment [μm]	53	11	30	61	71
Quadrupole roll [μrad]	511	38	200	1000	374
Quadrupole jitter [nm]	264	76	231	290	230

LBNL contributing to coupling studies at the KEK-ATF

- LBNL, SLAC and KEK collaborating in detailed Beam-Based Alignment and emittance tuning studies using new techniques at the ATF
- High performance diagnostics provide a unique opportunity for developing advanced tuning procedures, e.g. non-invasive dispersion measurements
- Vertical emittance < 5 pm is necessary for studies of Intrabeam Scattering and Fast Ion Instability to confirm effects in Damping Rings

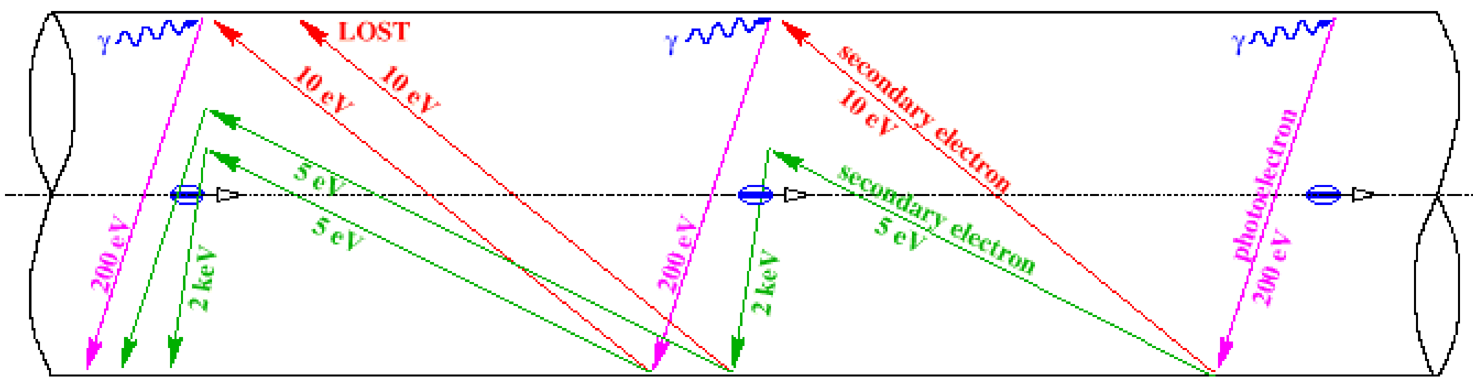




Dispersion measurements obtained from energy jitter ~ 5×10^{-5} using Model Independent Analysis (black lines) compared to standard measurement from RF frequency variation (colored points). The error in the MIA dispersion measurement is estimated at 1 mm , so the effective BPM resolution is of order 50 nm.

Electron Cloud could impact DR performance

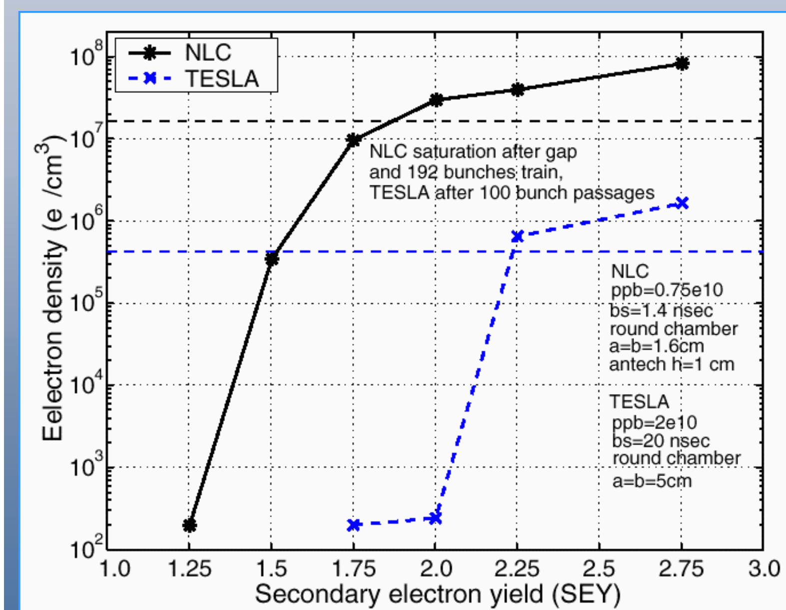
- Free electrons generated by a variety of processes
  - Photoemission from synchrotron radiation
  - Gas ionization
  - Secondary electrons from primary electrons impacting chamber



- Under certain conditions, electron density in the chamber can increase rapidly
  - Density tends to saturate at neutralization
  - Density of electrons is not uniform, and can be much larger close to the beam
- A dense electron cloud gives a strong coupling between single bunch and multi-bunch oscillation modes, leading to instabilities
- Observations at various positron and proton machines…

Electron Cloud may be eliminated by reducing SEY

- Secondary Electron Yield (SEY) key to the cloud formation
- Simulation of the build-up of the electron cloud in the damping rings, by Mauro Pivi, using a code by Miguel Furman
  - Code includes detailed model of secondary yield process
  - Benchmarking has been done against a number of operating machines
- Results indicate that SEY <1.3 will be needed in NLC damping rings
  - May be achievable with titanium nitride
  - Collaborating with BNL and SLAC to study effects of conditioning on the secondary yield of TiN surfaces



Saturation level of the electron cloud in the NLC and TESLA damping rings, as a function of the chamber SEY.

Samples of TiN coatings produced under various conditions by BNL for SNS Accumulator Ring.

Summary

- Evaluation of previous NLC damping ring designs motivated new designs to reduce impact of collective effects
- New designs for NLC have been completed
  - Main damping rings, predamping ring and transport lines
  - Main parameters meet (or exceed) specifications
  - Magnet parameters and layouts look reasonable
- New tools developed for modeling wiggler dynamics
  - Applied to NLC and TESLA
  - Plans to study wiggler effects in CESR-c
- Required NLC vertical emittance has been achieved at the ALS
  - Also working with SLAC and KEK to reach <5 pm at the ATF
- Studies of collective effects so far look encouraging
  - New NLC lattices have higher thresholds for microwave instability and coherent synchrotron radiation
  - Intrabeam scattering and fast ion instability need further study
  - Finding a way to eliminate the electron cloud is a priority